THE TURBULENT SCAR REGION IN THE WAKE OF A SURFACE SHIP

Final Technical Report for NRL Grant No. N00014-89-J-2008

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Introduction

This document represents the Final Technical Report for NRL Grant No. N00014-89-J-2008, "The Turbulent Scar Region in the Wake ~~of a~~ Surface Ship" -- period of performance April 1, 1988 through September 30, 1991. The research conducted under this grant was greatly enhanced by our concurrent participation in the Surface Ship Wake Consortium having membership (aside from ours) from the University of Michigan, the Massachusetts Institute of Technology, the U.S. Naval Research Laboratory and the David Taylor Research Center. The research was also enhanced by our collaborative participation in the Surface Ship Wake Detection Program.

25 * Surface waves, * wave detectors, * Ocean waves, Wake.

Technical Objectives and Issues

It has been established through a series of field experiments that sufficient amounts of surface-active organic materials accumulate in the wake of a surface ship to cause significant reductions in the surface tension across portions of the wake vis-a-vis the ambient surface tension of seawater. Such accumulations of surfactant material are known to damp strongly ocean waves of less than 15 to 20 cm in wavelength. Hence, it seems probable that the observed accumulations of surfactant materials play a critical role in the formation and persistence of the long, narrow, "dead

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Statement A per telecon Dr. Owen Griffin
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water" region occurring in the wake of a surface ship. Our first objective was to synthesize a model to determine the effects on the ambient wave field of a measured distribution of surfactants in the wake of a surface ship.

The same series of field experiments revealed that the transverse currents generated by the passage of a surface ship were larger in magnitude and persisted further downstream than predicted by standard turbulent wake models. Such currents influence ambient waves directly and also provide a mechanism to set-up and maintain bands of compacted surface-active organic materials. Our second objective was to develop and exercise a "bubble plume" model to assess the possible contribution of rising bubbles in the wake of a surface ship to the transverse surface currents in the wake.

Technical Accomplishments

We have synthesized a model that describes the interaction between the wake produced by a surface ship and the ambient wave field. The model includes wave damping by surfactants and turbulence and wave regeneration by wind and nonlinear energy transfer. This model has been applied to measurements and observations made during the West Coast Ship Wake Observability Exercises in 1989. Our results (Peltzer et al, 1990; Peltzer et al, 1991), which are in good quantitative agreement with wake measurements, indicate that surfactant films play an important role in the formation and persistence of the centerline wake region and that this role is probably dominant in the far wake. In the near and intermediate wake regions, other influences on wave energy

cannot be neglected -- especially at L-band where it is necessary to invoke wake damping by turbulence to explain the SAR observations.

We have developed and exercised a "bubble plume" model (Sodhi, 1991) to assess the possible contribution of rising bubbles in the wake of a surface ship to the transverse surface currents in the wake. The model is based on a three domain representation of a bubble plume with asymptotic matching between the domains. Using literature values for the constants in the model, we have found induced transverse surface currents on the order of 5 to 10 cm/s in the intermediate wake region. These results indicate that rising bubbles may contribute substantially to the hydrodynamic flow field in the wake of a surface ship.

Significance of Accomplishments

Our model for predicting wave damping and regeneration in the centerline wake region of a surface ship has provided good quantitative agreement with measurements made during the West Coast Ship Wake Observability Exercises. These results indicate that we have isolated the most important factors governing the persistence of the centerline wake region. However, several terms in the model are understood only very approximately and a host of questions remain to be answered before a complete physical description of this region can be formulated. Among these questions are the detailed processes of wave regeneration by wind and nonlinear energy transfer and the wake flow and turbulence induced by rising and bursting bubble plumes.

Publications

The following publications resulted, in whole or in part, from the research conducted under NRL Grant No. N00014-89-J-2008.

Refereed Journals

R.A. Skop, W.G. Lindsley and J.W. Brown (1991). "Radiotracer Studies of Surfactant Transport to the Sea-Air Interface by Submillimeter-Size Bubbles," Experiments in Fluids, V. 10, pp. 251-256.

W.G. Lindsley, R.A. Skop and J.W. Brown (1991). "Surface Pressure and Wave-Damping Effects of Surface-Active Organic Compounds on Seawater," Ocean Engineering, V. 18, pp. 593-601.

J.W. Brown, R.A. Skop, J. Viechnicki and R.-S. Tseng (1992). "Transport of Surface-Active Organic Materials from Seawater to the Air-Water Interface by an Ascending Current Field," Fluid Dynamics Research, in press.

Conference Proceedings

R.D. Peltzer, J.H. Milgram, R.A. Skop, J.A.C. Kaiser, O.M. Griffin and W.R. Barger (1990). "Hydrodynamics of Ship Wake Surfactant Films," Proceedings of the 18th Symposium on Naval Hydrodynamics, Ann Arbor, MI.

Technical Reports

R.D. Peltzer, R.A. Skop, J.H. Milgram, J.A.C. Kaiser and O.M. Griffin (1991). "Surfactant-Wave Interactions (Unclassified title, Unclassified appendix)," Appendix 6 of Volume II of JHU/APL Report S1R-91S-004 (Secret report).

Theses and Dissertations

W.G. Lindsley (1989). "Surface Pressure and Bubble Transport of Surface-Active Compounds in Seawater," M.S. Thesis, University of Miami, FL.

R.S. Sodhi (1991). "Study of a Two Dimensional Subsea Buoyant Plume as a Mechanism for Transverse Velocities in a Ship Wake," M.S. Thesis, University of Miami, Miami, FL.

Participants

The following investigators participated in the research conducted under NRL Grant No. N00014-89-J-2008.

Richard A. Skop, Principal Investigator, Professor, Division of Applied Marine Physics.

John W. Brown, Co-Principal Investigator, Research Associate Professor, Division of Applied Marine Physics.

Ruo-Shan Tseng, Rosenstiel Post-Doctoral Fellow, Division of Applied Marine Physics.

William G. Lindsley, Graduate Assistant, Division of Applied Marine Physics (MS obtained June 1989).

Rajpal S. Sodhi, Graduate Assistant, Division of Applied Marine Physics (MS obtained December 1991).